FLOOD PREDICTION
MAGNITUDE AND FREQUENCY

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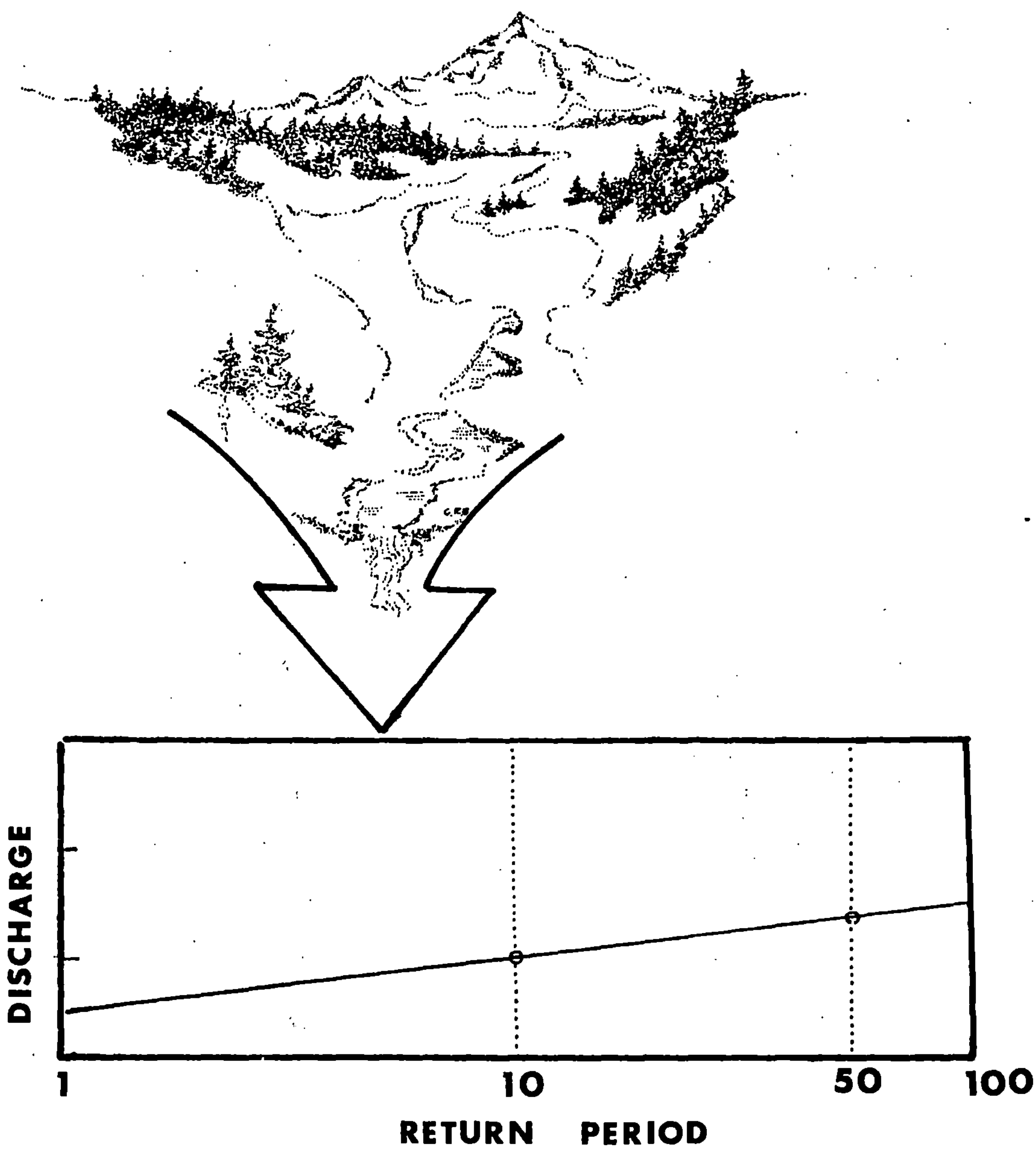

Prediction of Flood Magnitude and Frequency on the Deschutes National Forest

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I. INTRODUCTION

Determination of the magnitude of flood events at specific return periods or levels of probability is an important consideration in the design of stream crossings. Accurate prediction of flood size can save the expenditure of dollars when estimates are based on broad regional guidelines which could result in overestimations and, therefore, oversizing or overdesigning. Conversely, accurate estimates can save capital investments when undersizing or underdesign leads to culvert or bridge washout.

The development of regionalized flood frequency equations can proceed in several ways. Most methods, however, are based on measured streamflow and watershed response during flood events. Through statistical modelling of gaged streams one can develop prediction equations which incorporate local soil, vegetation, watershed, and climatic factors. These equations may then be used to predict flows from streams which are ungaged. The objective of this report is to provide the user with a means of predicting flood flows for return periods up to 100 years on ungaged and unregulated streams on the Deschutes National Forest.

II. FLOW CHARACTERISTICS OF THE DESCHUTES NATIONAL FOREST

Streamflow response and variation on the Deschutes National Forest has been summarized graphically by McCammon (1979). Evaluation of the flow duration curves in the above report leads one to conclude that there are three major types of streams on the Forest. These are: (1) spring-driven streams, (2) perennial streams, and (3) intermittent streams. These streams vary in runoff characteristics based on drainage area, precipitation rates, elevation, ground water influence, and within watershed storage capibility.

Figure 1 shows that a quantitative similarity exists between streams based on (1) mean annual flood, (2) drainage area, and (3) mean annual runoff. The three groups formed using a cluster analysis confirm the casual conclusion derived through inspection of flow duration curves for these streams; Group 1 is composed of "normal" perennial streams, Group 2 is made up of spring-driven streams or streams which originate from large lakes, and Group 3 is intermittent streams.

The relative degree of similarity is indicated by the position of the bar connecting two streams or groups of streams. Streams which respond very similarly are connected on the extreme right of the dendrogram (Squaw Creek and Tumalo Creek). Figure 1 shows that the Deschutes River below Snow Creek responds like Squaw Creek and Tumalo Creek, but at a very low degree of similarity.

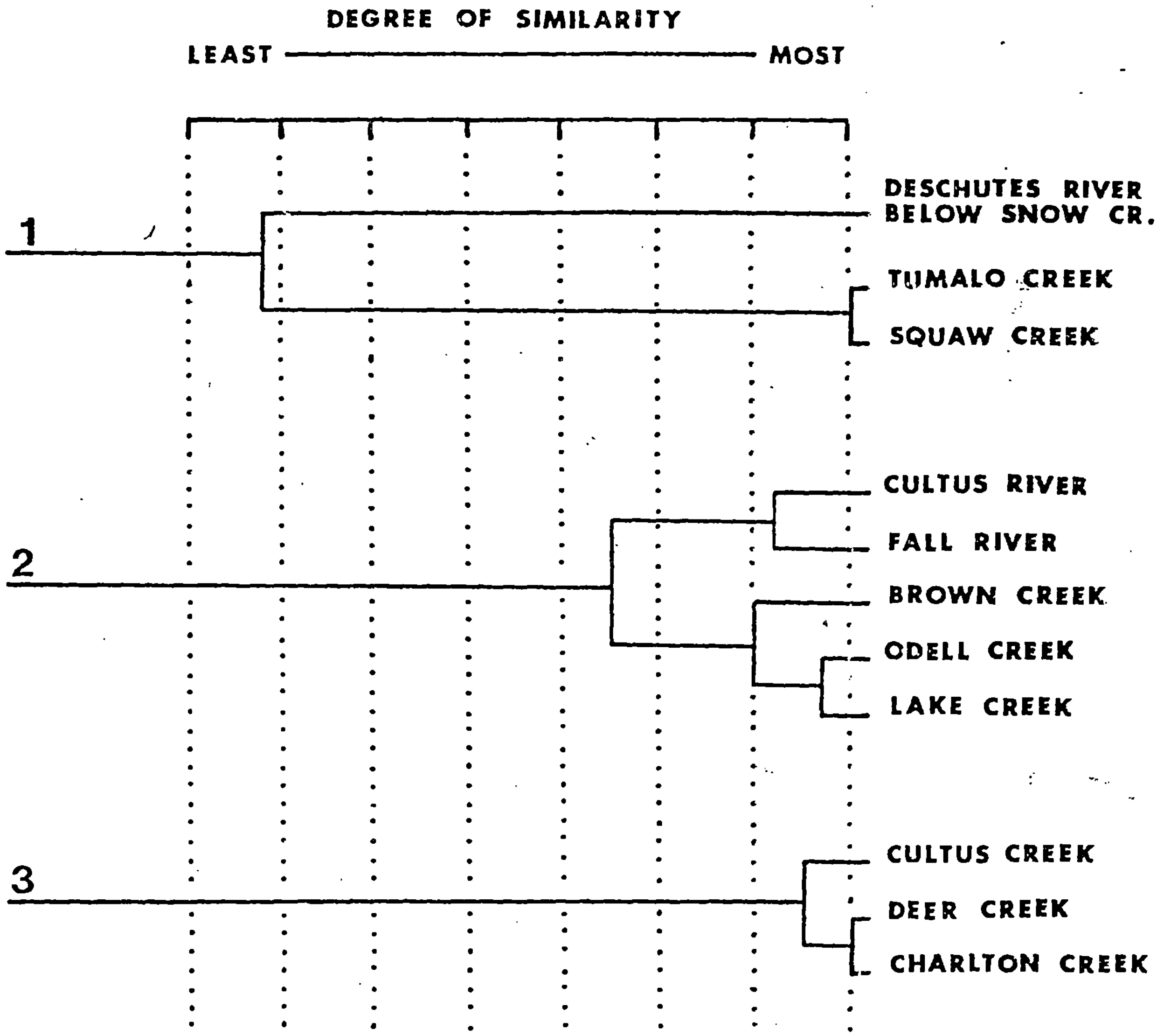


FIGURE 1.

Cluster dendrogram of streams based on mean annual flood, drainage area, and mean annual runoff.

III. METHODOLOGY

For each of the stations listed in Table 1 annual series data of daily maximum flows (cfs) were analyzed and fit to a log Pearson-type III frequency distribution. This is the method recommended by the Water Resources Council (1976) for use by Government agencies.

For each station analyzed (except Big Marsh Creek) data for the period 1945 to 1977 were used. Big Marsh Creek data consisted of 33 years of data between 1912 and 1957.

The method used by the U.S. Geological Survey in 1964 was followed to develop the equations. The reader might ask "Why not use the equations the USGS developed?" It was my feeling that new equations should be developed because:

1. The USGS did not use a log Pearson-type III analysis to determine their flood values (they fit a line to the data visually).

2. The equation given by the USGS covers all streams in the Lower Columbia basin on the east side of the Cascades.

The intent of this exercise was to refine the USGS prediction equation to where it was based on local rather than regional data.

Table 1

Streams used in log Pearson-type III analysis

Stream	Drainage Area (Square Miles)
Deschutes River below Snow Creek	132.0
Tumalo Creek	47.3
Squaw Creek	54.8
Big Marsh Creek	51.5
Cultus River	16.5
Fall River	45.1
Brown Creek	21.0
Odell Creek	39.0
Lake Creek	22.2
Cultus Creek	33.2
Charlton Creek	15.6
Deer Creek	21.5
Metolius River	316.0

The first step in the process was to conduct a homogeneity test on the stations to ensure that they were statistically related and could be modelled as one group. This test is described by Dalrymple (1960). The results of the computations are shown in Table 2 and Figure 2. Streams which are plotted between the curved boundaries in Figure 2 may be treated as one group.

Table 2
Homogeneity Test

	$Q_{2.33}$	Q_{10}	Ratio Q_{10} to $Q_{2.33}$	1.53 1/ Times $Q_{2.33}$	Period of Record Years	Return Period For Q in Col. 4
Deschutes below Snow Cr.	298	405.6	1.36	455.9	33	49
Cultus River	98	131.0	1.34	149.9	33	40
Cultus Creek	125	210.0	1.68	191.3	33	8
Deer Creek	59	83.1	1.41	90.3	33	17
Brown Creek	56	73.1	1.31	85.7	33	90
Odell Creek	231	427.8	1.85	353.4	33	7
Little Deschutes	675	1,254.5	1.86	1,032.8	33	8
Fall River	184	221.0	1.20	281.5	33	100+
Tumalo Creek	425	582.5	1.37	650.3	33	24
Squaw Creek	455	718.2	1.58	696.2	33	10
Lake Creek	184	314.6	1.71	281.5	33	10
Metolius River	2,530	3,786.3	1.50	3,870.9	33	12
Charlton Creek	22	34.5	1.59	33.7	33	8
Big Marsh Creek	295	490.8	1.66	451.4	33	7
		Mean =	1.53			

1/ 1.53 = average of Q_{10}:$Q_{2.33}$ ratios

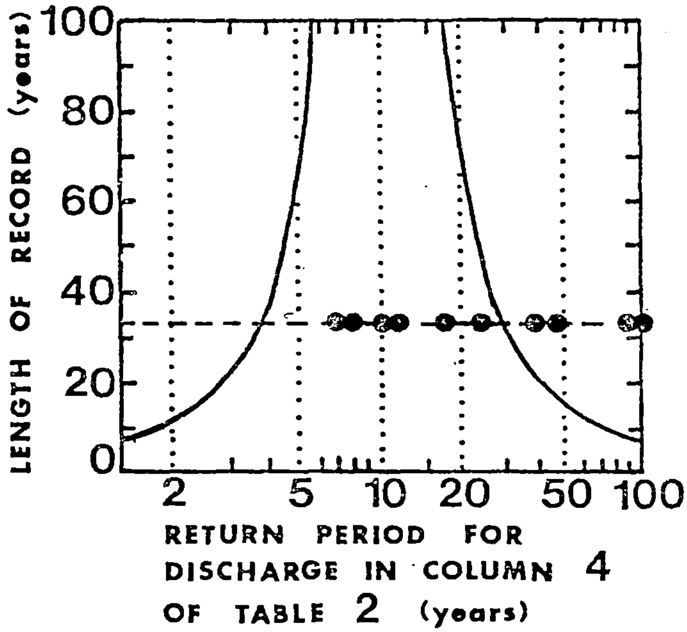


FIGURE 2.

Homogeneity Test

The four streams which plot outside the curved boundaries are all streams with strong groundwater influences. The test results, therefore, indicate that the data should be modelled as two groups. It is interesting to note that the USGS did not include Fall River in their analysis and concluded that all streams on the east side of the Cascades could be treated as one group. This shows the influence which stations outside the Deschutes River Basin had on the development of the USGS equation. Also, the degree of similarity indicated between the Deschutes River below Snow Creek and Squaw Creek and Tumalo Creek (Figure 1) is not strong enough to satisfy the homogeneity test.

The mean annual flood of a stream is a function of many items: drainage area, precipitation, vegetation, geology, physical shape, slope, altitude, storage capacity, and annual runoff. The USGS has analyzed the merit of including each of these variables in the prediction equations. They have determined that drainage area, mean annual runoff, and storage capacity are very important. Analysis of residuals after developing their equations showed that a geographic factor which relates to soil permeability, slope, and altitude helps to increase the predictive capability of the equations. Geographic factors ranging from 0.20 to 0.65 are in very permeable lava areas in or near the Cascade Crest. Factors of 0.80 to 1.00 are found in areas of either low runoff, flat slopes, permeable soils, medium-to-low altitudes or combinations of these. Geographic factors from 1.10 to 2.05 are associated with impermeability, steep slopes, medium-to-high altitudes, high runoff, or combinations of these.

The factors which are included in the development of an equation for prediction of mean annual flood are:

1. Drainage basin area - square miles.

2. Annual runoff - inches.

3. Percent of basin which is lakes and ponds.

4. Geographic factor.

The data input to a stepwise multiple regression analysis program was the logarithms to the base 10 of the values given in Table 3.

Table 3
Equation Development Data

Spring-Driven Streams	$Q_{2.33}$	DA	RO	G	L
Deschutes River below Snow Creek	298	132.0	16.0	0.65	2.04
Cultus River	98	16.5	52.5	0.65	0.61
Fall River	163	45.1	46.1	0.65	0.35
Brown Creek	56	21.0	25.5	0.65	0.46
Other Streams					
Tumalo Creek	425	47.3	29.3	0.80	0.11
Squaw Creek	455	54.8	26.3	1.25	2.74
Cultus Creek	125	33.2	9.4	0.65	7.24
Deer Creek	59	21.5	4.8	0.65	2.79
Odell Creek	231	39.0	28.4	1.00	12.80
Little Deschutes	500	859.0	3.3	0.85	2.00
Lake Creek	184	22.2	32.3	0.90	4.96
Metolius River	2,720	324.0	58.6	0.90	0.43
Charlton Creek	22	15.6	1.2	0.65	1.60
Big Marsh Creek	295	51.5	18.2	1.00	0.39

Where $Q_{2.33}$ = mean annual flood (cfs), DA = drainage area (sq. miles), RO = mean annual runoff (inches), G = geographic factor, and L = percent of basin area which is lakes and ponds.

The equations which result from the analysis are:

1. Spring-driven streams with geographic factor less than 0.90.

$$Q_{2.33} = 0.437\ DA^{0.952}\ RO^{0.643}$$

$$R^2 = 0.97$$

2. Other streams.

$$Q_{2.33} = 3.298\ DA^{0.658}\ RO^{0.661}\ G^{0.141}\ L^{-0.097}$$

$$R^2 = 0.99$$

By plotting the average values of $Q_{tr}/Q_{2.33}$ values obtained in log Pearson-type III analysis with the return period (tr) ranging from 1.01 to 100 for the two groups we can establish composite flood frequency graphs which will allow prediction of flood flows at any given return period. Figure 3 shows this relationship for the two types of streams. The ratios of Q_{tr} to the mean annual flood, $Q_{2.33}$, are given in Table 4.

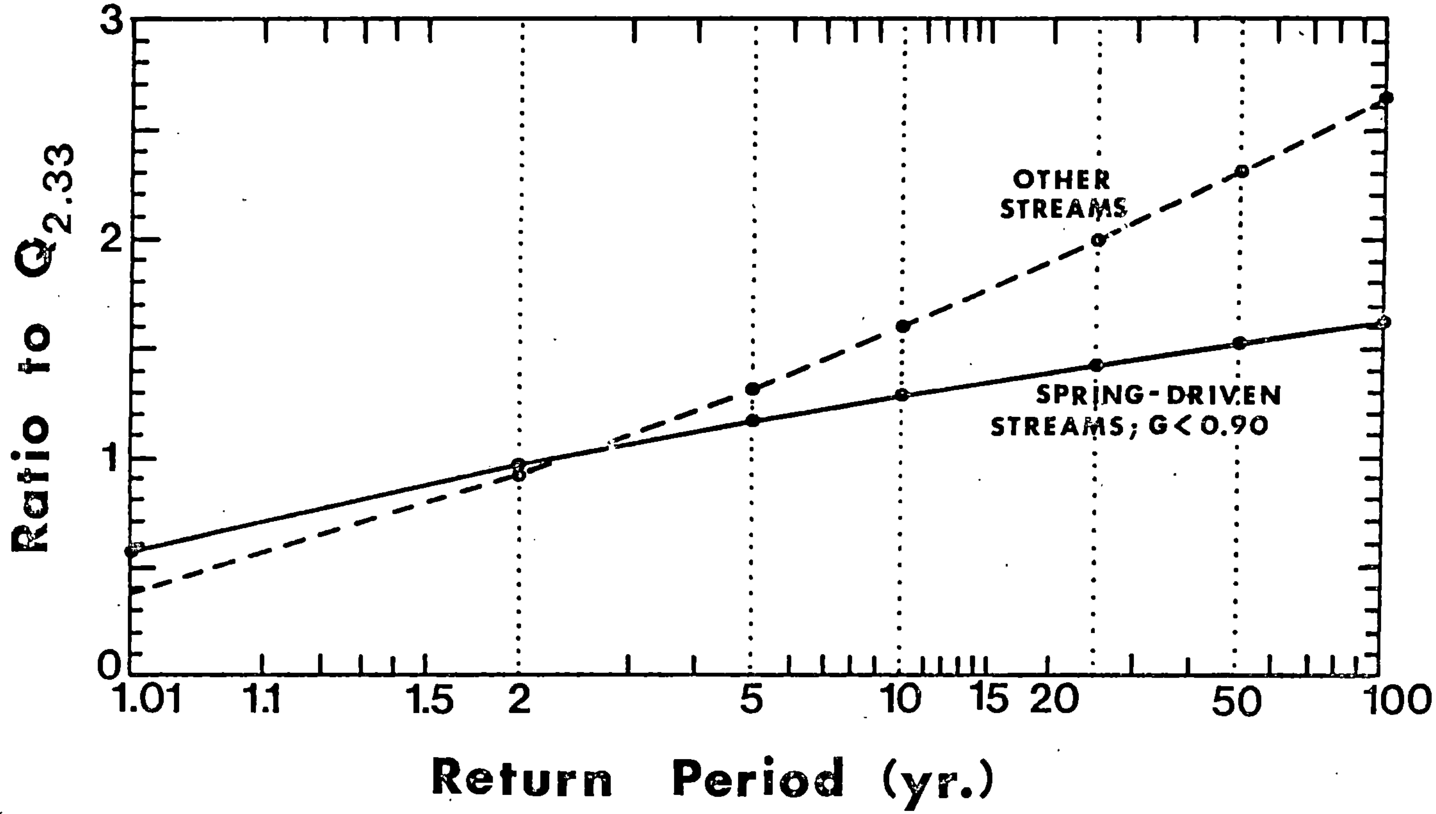


FIGURE 3.

Ratio of flood flow to mean annual flood for return periods from 1.01 to 100 years

Table 4
Average Ratio of Flows at Selected
Return Periods to the Mean Annual Flood
($Q_{tr}/Q_{2.33}$)

	Q_{tr}						
	1.01	2	5	10	25	50	100
Spring-driven streams with G less than 0.90	0.53	0.97	1.18	1.30	1.44	1.54	1.63
Other streams	0.38	0.94	1.34	1.62	2.01	2.32	2.66

By using the equations developed and Figure 3, we can now estimate flood flow for any ungaged watershed on the Deschutes National Forest.

IV. EXAMPLE OF USE

We want to construct a bridge over Whitefish Creek near Crescent Lake. After drawing the watershed boundary above the bridge site we determine that:

1. Drainage area = 30.6 square miles.

2. Percent of drainange area which is lakes or ponds = 1 percent.

From maps 1 and 2 we estimate that:

3. Annual runoff = about 25 inches.

4. Geographic factor = 0.90.

Since Whitefish Creek is not a spring-driven stream we can estimate the mean annual flood using the following equation:

$$Q_{2.33} = 3.298\ DA^{0.658}\ RO^{0.661}\ G^{0.138}\ L^{-0.097}$$

$$Q_{2.33} = (3.298)(30.6^{0.658})(25^{0.661})(0.90^{0.141})(1.0^{-0.097})$$

$$= (3.298)(9.50)(8.40)(0.99)(1)$$

$$= 260.6 \text{ cfs}$$

$$= 260 \text{ cfs}$$

We want this bridge to have a design life of 35 years with a 30 percent chance of failure. Referring to Table 5 we find that we should be using a 99 year return period for the design flow. For simplicity we will compute the 100 year flood.

Referring to Figure 3 we find that:

$$\frac{Q_{100}}{Q2.33} = 2.66$$

The 100 year flood at this location may now be computed.

$$Q_{100} = \frac{Q_{100}}{Q2.33}\ (Q2.33)$$

$$= (2.66)(260)$$

$$= 692 \text{ cfs}$$

If we had used the procedure as given in the USGS book for the Lower Columbia River Basin, the values we would have gotten are:

$$Q_{2.33} = (2.36)(30.6^{0.80})(25^{0.62})(1^{0.17})(0.90)$$

$$= 241 \text{ cfs}$$

$$Q_{100} = (Q_{2.33})(1.9)$$

$$= 457 \text{ cfs}$$

The USGS value represents a 34 percent reduction in peak flow or the equivalent of designing to pass a 15 year flood.

V. PRECAUTIONS

Neither of the equations presented in this paper should be used directly for drainage areas less than 15 square miles. Using 15 square miles as a lower limit of acceptibility represents a slight extrapolation of the equations beyond the limits of the data used for equation development. It is felt that this extrapolation will not result in errors greater than 1 percent of the prediction capabilities of the equations.

For drainage areas less than 15 square miles the following procedure should be followed.

1. Measure drainage area (DA) in square miles.
2. Predict $Q_{2.33}$ using the appropriate equation and a drainage area of 15 square miles.
3. Compute the design flow for 15 square miles using $Q_{2.33}$ and Figure 3 or Table 4.
4. Divide the actual drainage area by 15.

5. For spring-driven streams with G less than 0.90 raise the quotient produced in No. 4 to the 0.69 power. For other streams, raise the quotient to the 0.77 power. These exponents are derived from exponential regressions of drainage area (DA) and mean annual flood ($Q_{2.33}$) for the two groups.

6. Multiply the design flow produced in No. 3 above by the product generated in No. 5.

7. The design flow for the area (less than 15 square miles) is the result of the multiplication performed in No. 6.

Example: Drainage area = DA = 6.3 square miles
runoff = RO = 40 inches
percent lakes and ponds = L = 1%
geographic factor = G = 0.9

1. Mean annual flood with DA = 15 square miles:

$$Q_{2.33} = 3.298\ (15^{0.658})(40^{0.661})(0.9^{0.141})(1^{-0.097})$$
$$= 221.1 \text{ cfs}$$

2. Design for 25 year flood (based on Table 5).

$$Q_{25} = (221.1)(2.01)$$
$$= 444.5$$
$$= 445 \text{ cfs}$$

3. Ratio of drainage areas = 6.3/15
= 0.42

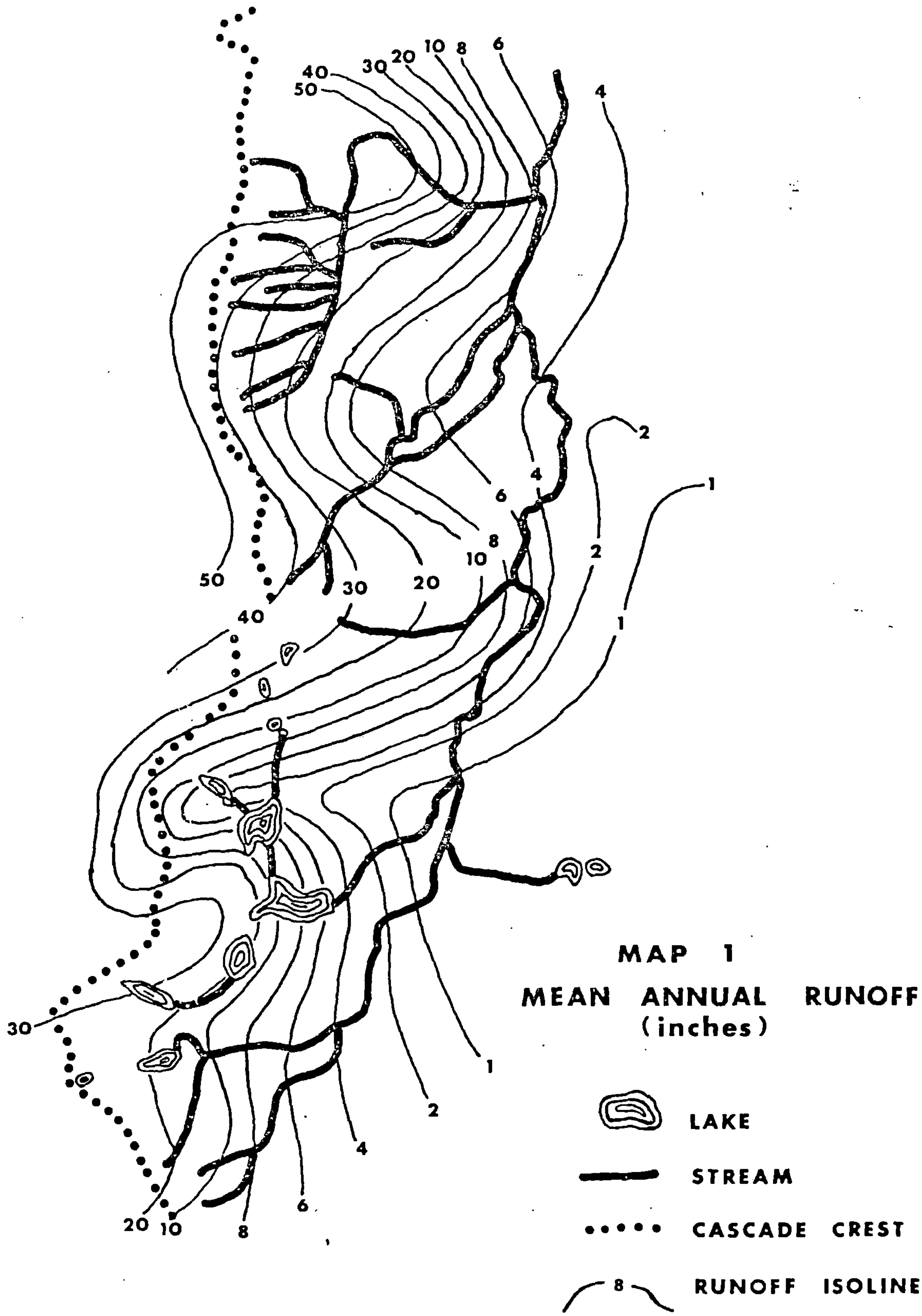
4. This is not a spring-driven stream with G less than 0.90, therefore, raise the value from No. 3 to the 0.77 power.

$$0.42^{0.77} = 0.51$$

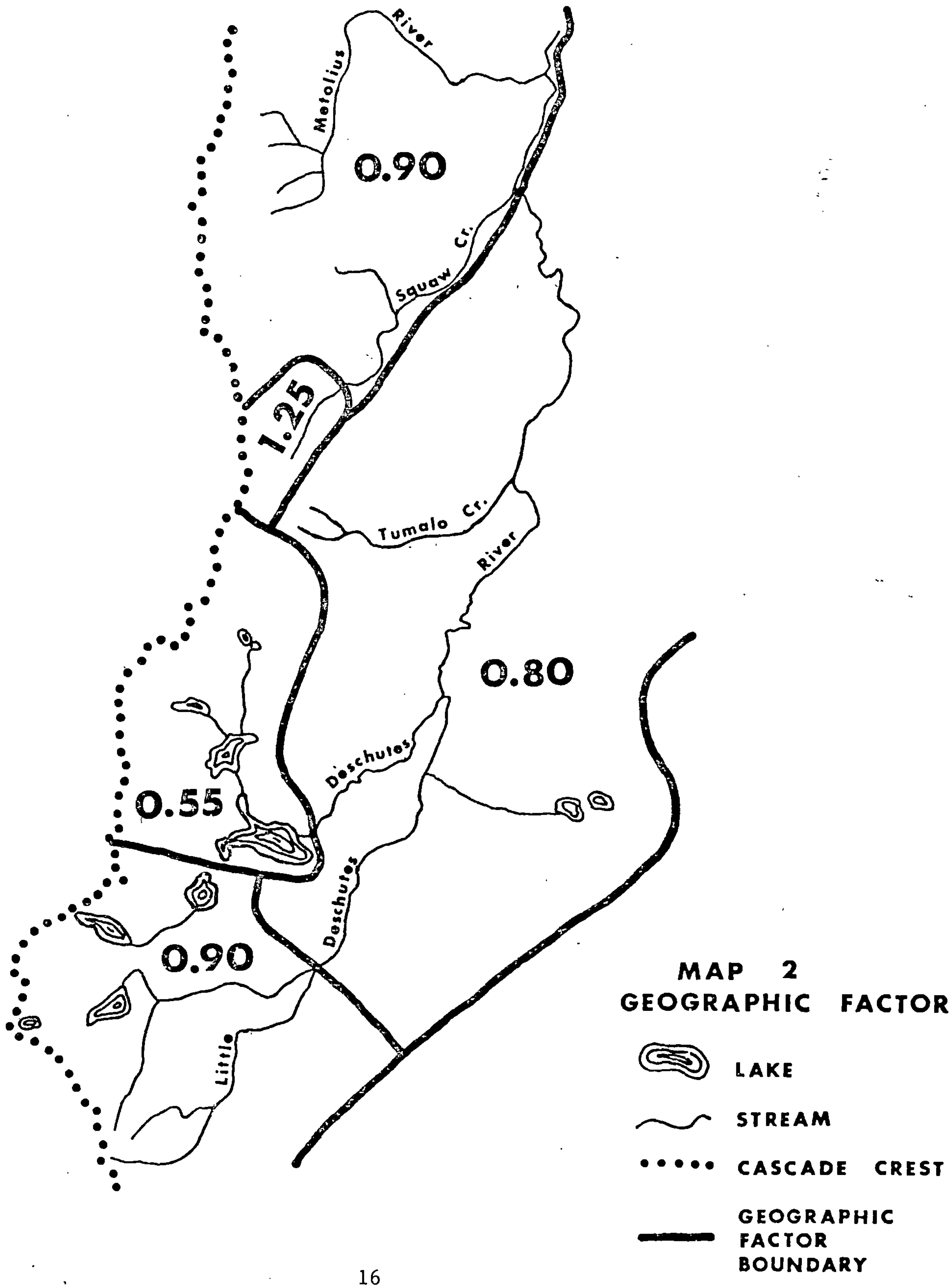
5. Design flow for 6.3 square miles = (445)(0.51)
= 227 cfs

TABLE 5
Calculated Risk Table
(Recurrence Interval in Years)

Design Life (years)	Percent Chance of Failure 5	10	20	30	40	50	60	70	80	90	95
1	20	10	5	4	3	2	2	2	2	2	2
3	59	29	14	9	7	5	4	4	3	2	2
5	98	48	23	15	11	8	6	5	4	3	3
8	156	77	37	23	17	13	10	8	6	4	4
10		96	46	29	21	15	12	9	7	5	4
15		143	68	43	30	23	17	13	10	8	6
20			91	57	40	30	23	18	13	10	8
25			113	71	50	37	28	23	17	12	9
30				85	60	44	34	26	20	14	11
35				99	70	51	39	30	23	16	13
40				113	79	59	45	34	26	18	14
45					89	66	50	38	29	21	16
50					99	73	56	43	32	23	18
60					118	88	66	51	38	27	21
70						101	77	59	44	31	24
80							88	67	51	36	28
90							99	76	57	40	31
100							110	84	63	44	34



MAP 1
MEAN ANNUAL RUNOFF
(inches)



Metolius River
0.90
Squaw Cr.
1.25
Tumalo Cr.
River
0.80
Deschutes
0.55
Deschutes
0.90
Little
MAP 2
GEOGRAPHIC FACTOR
LAKE
STREAM
CASCADE CREST
GEOGRAPHIC FACTOR BOUNDARY

BIBLIOGRAPHY

Dalrymple, T. 1960.
Flood-frequency analysis. USGS Water Supply Paper 1534-A.

McCammon, B. 1979.
Streamflow characteristics of the Deschutes National Forest, unpublished USFS report, 81p.

U.S. Geological Survey. 1964.
Magnitude and Frequency of Floods in the United States. Part 14: Pacific Slope Basins in Oregon and Lower Columbia River Basin, Water Supply Paper 1689.

U.S. Water Resources Council, 1976.
Guidelines for determining flood flow frequency, Bull.17 of the Hydrological Commission.